As discussed below, CD Radio's extensive experimentation clearly demonstrates that CD Radio's technology is technically feasible.

CD Radio is, in fact, the first, and at least until the filing of this pleading, remains the only, company to test satellite DARS empirically and report results to the Commission. As early as October of 1991, CD Radio's "Early Bird" system demonstrated stereo reception of CD-quality DARS with multiple channels to a fixed receiver. Although the test system differed in respects from CD Radio's satellite DARS system design, CD Radio's tests nonetheless confirmed critical aspects of CD Radio's system design and commercially validated the subscription satellite DARS concept.[30]

CD Radio's testing, however, did not stop in 1991. Since that time, CD Radio has been able to feed back the results of its Early Bird tests into its system design, and has now fully developed and validated its satellite DARS system technology. CD Radio has attached, as Exhibit A, a field report of these recent tests, which conclusively confirm the technical feasibility and commercial practicality of CD Radio's system design. In particular, CD Radio's latest tests demonstrated:

- The feasibility of satellite delivered DARS in the S-Band frequencies in a typical multipath environment;
- Mobile reception of DARS signals duplicating received power levels and elevation angles representative of CD Radio's technical designs, including reception through underpasses that would block a non-diverse system;

[30] Unlike CD Radio's final system design, the 1991 Early Bird tests used 256 kb/s digital audio data; required 2 MHz per channel of audio data; employed 12" x 12" high-gain directional receive antennas designed by and produced for CD Radio; functioned within a relatively ideal multipath environment; and received on frequencies in the C-Band.

- Extremely small, low-gain roof-recessed omnidirectional antennas;
- A fully developed and human-engineered automobile radio interface and mobile receiver; and,
- 30 channels of digital audio data, at data rates of 128 kb/s using PAC, with a multiplexed 128 kb/s data channel, in two 8 MHz channels.

These results empirically validate CD Radio's satellite DARS system design, providing the ultimate demonstration of feasibility.

For the tests, CD Radio selected a location a few miles in each dimension, which included areas shadowed by buildings, trees, and overpasses. To simulate the spatial diversity of the CD Radio satellite DARS architecture, CD Radio placed transmitters on the rooftops of a number of tall buildings in such a way as to duplicate the elevation angles in the deployed system. The effective radiated power of the transmitters was attenuated to provide a signal level equivalent to the level that would be provided by the geostationary satellites under CD Radio's design. All transmitters utilized frequencies in the S-Band currently proposed for satellite DARS operations, with a frequency offset to achieve diversity.

CD Radio's field trials also used a prototype satellite DARS receiver that CD Radio designed, constructed, and integrated into a conventional car audio system. Using this receiver and CD Radio's silver dollar-sized planar array antenna, CD Radio was able to explore both reception of satellite DARS signals as well as network control over remote mobile receivers. The system also implemented all of the control and display functions of the CD Radio DARS system, enabling CD Radio to test user acceptance of the human interface.

CD Radio's test system thus replicated, to the extent possible, all aspects of its satellite DARS architecture. Using this system, CD Radio was able to receive emulated satellite signals with minimal signal blockage[31] and logged empirical results consistent with its expectations. These data are further explored in the experimental report attached as Exhibit A. With the system technology fully developed and experimentally verified, CD Radio's remaining tasks are optimization of system design parameters, testing in different geographic markets, and component miniaturization.

Others may falsely claim to be pioneers or protest CD Radio's inventiveness. But none of these entities have come close to duplicating CD Radio's accomplishments: two real world oriented tests; a working consumer-quality radio; and a tiny and practical, yet workable antenna. CD Radio stands ready to inaugurate satellite radio services, has formulated the technology to do so and demonstrated the viability of that technology through focused experimentation at a cost of approximately $1 million. These actions, unique among the satellite DARS applicants, are truly those of a pioneer.

---

[31] Indeed, CD Radio's success at overcoming signal blockage due to overpasses, in many cases, was spectacular. For example, Appendix A, Attachment A1 at page 4 contains a chart showing received signal levels for two spatially independent paths empirically measured at 10 foot increments around an overpass in the test area. Although both signals independently show substantial blockage (*i.e.*, signal level change of -12 to -20 dB in only 40 feet), the overall signal quality obtained by selecting the stronger frequency (not even combining the signals) remains within 1 dB of the satellite normalized operating level at -31 dBm. Under the circumstances, a subscriber travelling under the overpass would not experience any disturbing signal blockage at all in CD Radio's deployed system, whereas the signal would most likely be rendered unusable in a single satellite design. *See generally* Appendix B at 2.

IV. CONCLUSION

CD Radio's efforts to create satellite DARS warrant grant of a pioneer's preference under the standards announced by the Commission. CD Radio transformed satellite DARS from nascent engineering concept to reality:

- CD Radio was the first to propose satellite DARS -- over three years ago and more than two and one half years before any other existing applicant;
- CD Radio invested time and resources in identifying and freeing spectrum, both nationally and internationally, for satellite DARS;
- CD Radio played an instrumental role in the administrative processes to create the service;
- CD Radio envisioned a ubiquitous, seamless satellite service, then pioneered important technical advances like spatial and frequency diversity in a mobile satellite architecture, and other satellite systems integration developments, enabling satellite DARS to be deployed on a truly coast-to-coast basis; and,
- CD Radio has exhaustively tested its designs in real world trials, fully validating its satellite DARS technical solutions.

These efforts and innovations should be rewarded by the Commission with a pioneer's preference to allow CD Radio, at long last, to deploy its system commercially.

Respectfully submitted,

SATELLITE CD RADIO, INC.

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June 2, 1993

CD RADIO

APPENDIX A

FIELD TEST REPORT
SATELLITE DIGITAL AUDIO RADIO SERVICE
EXPERIMENT

CD RADIO INC.

June 2, 1993

CD Radio Inc.
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EXECUTIVE SUMMARY

FIELD TEST REPORT
SATELLITE DIGITAL AUDIO RADIO SERVICE
EXPERIMENT

Pursuant to its experimental license[1], CD Radio has conducted field tests of its Satellite Digital Audio Radio Service. The purpose of these tests was to evaluate the operational capabilities of the CD Radio system design in a real world mobile environment at S-band. As detailed in this report, the demonstrated results of the experiments confirmed the technical feasibility of the CD Radio system design.

An emulation of the satellite link and a prototype satellite mobile receiver were assembled in CD Radio's technical facilities in Washington, DC. A test range was established at a site in northern Virginia close to downtown Washington, DC. With the assistance of AT&T Bell Laboratories, Ford Electronics Division, ComStream Corporation and Seavey Engineering, CD Radio's engineering staff assembled a mobile test facility for Satellite Digital Audio Radio Service (Satellite DARS). This test facility consists of a test range containing a drive path of approximately 3.5 miles in length , a studio facility capable of simultaneously transmitting 30 channels of CD quality compressed music through a satellite, a satellite DARS receiver integrated into a conventional automobile, and a satellite DARS car radio human engineered for the motorist.

The experiments verify that:

- o CD Radio's use of satellite spatial diversity significantly reduces blockage;

- o CD Radio's use of satellite spatial and frequency diversity

[1] CD Radio Inc. Experimental Radio authorization KO2XES, File No. 3481-EX-PL- 92 (February 25, 1993).

substantially reduces multipath fading;

- o The audio compression algorithm chosen by CD Radio provides CD quality stereo music in a car when operating at 128 kb/s;

- o CD Radio's small low gain omni-directional receive antenna is suitable for automobile use;

- o A bandwidth of 8 MHz will support 30 channels of stereo music and one control channel; and,

- o Effects of interference at S-band is inconsequential.

With these results, CD Radio has demonstrated that its system design for satellite DARS is practical and ready for implementation.

CD Radio has consistently led the effort to build a satellite DARS system for the citizens of the United States. CD Radio was the first to design a satellite DARS system and file a license application at the FCC. In this experiment CD Radio was the first to demonstrate satellite DARS at S-band.

This report is a direct continuation of CD Radio's satellite DARS development work reported to the FCC in January 1992[2]. CD Radio's ongoing program will continue to demonstrate the satellite DARS system described in this report. Additional areas of testing may include statistical sound quality tests, refinements to the satellite receiver signal processing and evaluation in geographically diverse areas and climates.

---

[2] Early Bird Experimental Report; January 23, 1992, Supplement to Request for Pioneer's Preference; FCC File RM-7400.

FIELD TEST REPORT
SATELLITE DARS EXPERIMENT

TABLE OF CONTENTS

EXECUTIVE SUMMARY

		Page
1.	INTRODUCTION	1
2.	EXPERIMENT OBJECTIVE	5
3.	PROGRAM OF RESEARCH AND EXPERIMENTATION	8
4.	TEST RESULTS SUMMARY	30
5.	CONCLUSIONS	38

ATTACHMENTS

- A1. TEST RESULTS
- A2 TEST RANGE DESCRIPTION
- A3 TEST SYSTEM
- A4 MUSIC PROGRAMMING
- A5 AT&T PAC MUSIC COMPRESSION ALGORITHM

FIELD TEST REPORT
SATELLITE DARS EXPERIMENT

1. INTRODUCTION

CD Radio has developed a nationwide CD-quality satellite-based all digital radio service primarily for passengers in automobiles. This service will provide motorists with a broad range of narrowcast music[3]. CD Radio subscribers will have 24 hour access to 30 channels of CD-quality sound anywhere in the continental United States.

Distribution of digital music by satellite to fixed sites is proven and expanding rapidly. Domestic satellite systems for land mobile voice and data communications are under construction and will soon go into service. CD Radio builds on this technical base to provide quality sound in the mobile environment. To meet this higher level of performance the CD Radio system design combines advanced satellite signal processing, psychoacoustic audio compression, and high power satellite technologies to provide its service. Central to the system design is the need to provide a satellite based medium bit rate digital channel to mobile vehicles equipped with small low gain omni-directional antennas .

Over the past three years CD Radio has focused its efforts on the detailed technical design of its system. In the Summer of 1991 this effort reached the point where it was desirable to test several CD Radio system design features. A test system was assembled and testing was completed in late 1991. In these tests CD Radio demonstrated the digital transmission of CD quality music via satellite to a small custom designed antenna and also tested subscriber interaction. This experiment was performed using commercial C-Band satellite transponder capacity. The results of these tests validated the CD Radio design features tested. A full report of these

[3]Narrowcast A narrowly focused broadcast music format targeted at satisfying a particular musical interest.

initial tests was submitted to the FCC in January 1992[4].

In the months following the initial tests, CD Radio continued to refine its system design. In October 1992 CD Radio embarked on a second and more extensive Satellite DARS Experiment to evaluate further the performance of its system design in a mobile environment. The CD Radio Test System for this second experiment is shown in Figure 1-1.

The band approved at WARC 92 for satellite DARS service in the United States is 2310 - 2360 MHz. This band is currently used sparsely by the United States government for terrestrial radio relay and telemetry. There is no commercial satellite capacity available in this or adjacent bands in the United States. Thus CD Radio needed to construct a terrestrial emulation of its planned system to demonstrate its satellite link design in a mobile environment. In December 1992 CD Radio applied for an experimental license to transmit its satellite DARS signal in the 2310 - 2360 MHz band from rooftop and tower located terrestrial transmitters. The experimental license was granted on February 25, 1993, and all testing was performed in accordance with this license.

The second CD Radio Satellite DARS experiment focused on evaluating the satellite-to-automobile link and psychoacoustic audio compression plus demonstrating the user interface. In this experiment CD Radio:

> Assembled a 30 music channel studio with psychoacoustic music compression and satellite signal generation equipment;
>
> Established a test mobile range using a terrestrial emulation of an S-band satellite;
>
> Developed a small low gain omni-directional S-band satellite receive antenna;

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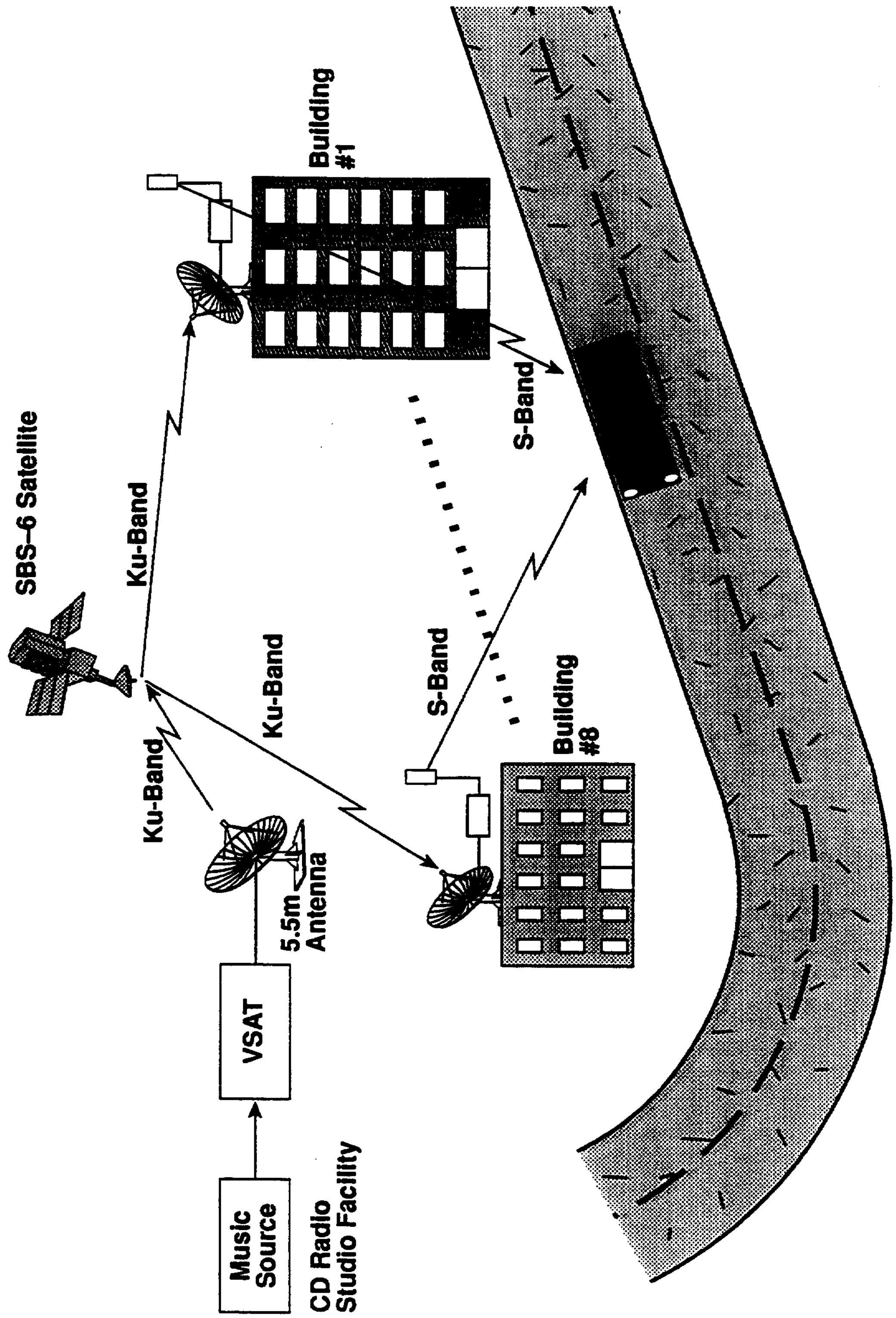
4 Ibid.

Figure 1–1 CD Radio Satellite DARS Experiment — Simplified Block Diagram



Instrumented an automobile with a satellite DARS receiver fully integrated into the existing automobile stereo system;

Human engineered and assembled an AM/FM/CD Radio dash board mounted car radio; and,

Conducted tests/evaluations in the mobile environment.

In its testing CD Radio has established that its system design is technically efficient and can be easily implemented. In particular, test results demonstrate that the CD Radio system can support 30 channels of CD-stereo sound in 8 MHz of bandwidth, that its signal diversity (spatial and frequency) concept mitigates fades due to blockages and multi-path, that its omni-directional circular polarized planar array antenna functions properly in the mobile environment and that a psychoacoustic encoding data rate of 128 Kb/s for a stereo channel pair provides CD quality sound.

The second CD Radio conducted Satellite DARS experiment was completed in May 1993. This report summarizes results of this second experiment.

2. EXPERIMENT OBJECTIVE

In May 1990 CD Radio applied to the FCC for permission to implement a multi-channel satellite DAR service to mobile vehicles in the continental United States. With its application to provide satellite DAR service, CD Radio publically began the development of a new service that would be of great benefit to the residents of the United States. When CD Radio filed its application it knew there were many technical obstacles to overcome. Since its initial filing CD Radio staff have diligently worked to remove these technical obstacles. The system design has been refined and adjusted to improve performance, while reducing complexity and cost. CD Radio has established an on-going experimental program to validate its technical design. The initial results of this program were filed with the FCC in January 1991[5].

The CD Radio system is designed to mitigate both the multipath fading and blockage encountered in a mobile environment. The CD Radio system design innovatively combines advanced satellite signal processing and audio compression technologies to achieve its required level of performance. The objective of this experiment is to provide an early test of system operation for an emulated mobile operating environment at radio frequencies in the S-band allocated to satellite DAR service.

In this experiment CD Radio validated all technically significant portions of the CD Radio Satellite DAR service system design. This validation was achieved through testing and demonstrating the technical feasibility of the selected satellite signal processing and audio compression algorithms. In this experiment, CD Radio, for the first time, tested these technologies together in an emulated mobile environment.

Based on the results of this experiment, CD Radio expected to show with a terrestrially emulated S-band satellite signal in a mobile environment:

---

[5] Ibid

1. *Satellite spatial diversity significantly reduces blockage;*

The test range was designed so that the drive path is covered by two signals containing the same music data but transmitted from physically separate sites. The test range was set up on public roads and is representative of the blockage expected in the operational environment. This includes buildings, trees, overpasses, and adjacent vehicles.

2. *Satellite spatial and frequency diversity mitigates multipath;*

The test range was designed so that the drive path is covered by two signals containing the same music data but transmitted at different frequencies and from physically separate sites. The test range was set up on public roads and is representative of the expected operational environment. This includes buildings, trees, overpasses, and adjacent vehicles.

3. *The sound quality of audio compression algorithms operating at 128 kb/s for a stereo channel;*

The AT&T Bell Laboratories developed PAC audio compression algorithm was used for music processing of all 30 music formats. This algorithm is designed to compress the music for transmission at a 128 kb/s rate for a stereo pair. The music formats covered the complete spectrum of listener tastes.

4. *The suitability of a small low gain omni-directional receive antenna; and,*

A 2 inch diameter prototype CD Radio antenna was embedded in the automobile roof and used in mobile tests to receive the S-band signal. This antenna has gain of approximately 3 dB within a 20° - 60° elevation angle at all azimuths.

5. *A bandwidth of 8 MHz will support 30 channels of stereo music.*

The entire 30 channels of music plus a control channel was multiplexed into a single bit stream at 3.968 Mb/s (31x128 kb/s). This was then subjected to a rate 1/2 viterbi FEC and OQPSK modulated on a single carrier. For frequency and spatial diversity, the resultant 4.7 MHz bandwidth was transmitted at two different frequencies in the S-band. This extrapolates to a bandwidth of less than 8 Mhz for rate 1/3 convolutional encoding forward error correction as planned by CD Radio, and when used in a frequency diversity configuration, requires less than 16 MHz of radio frequency bandwidth.

Further, as part of this experiment, CD Radio explored operational aspects of its system. This included network control over remotely located mobile receivers, receiver display/control features and vehicle user service acceptance. A prototype satellite DARS receiver interface was designed, constructed and integrated into a conventional car audio system. The prototype receiver implements all of the control and display functions of the CD Radio satellite DARS system. User acceptance of the human interface was explored.

3. PROGRAM OF RESEARCH AND EXPERIMENTATION

3.1 GENERAL

CD Radio Inc. is currently developing a nationwide CD-quality satellite digital radio service primarily for passengers in automobiles. This service utilizes a portion of the band assigned to satellite DAR service in the United States (2310 -2360 MHz) for its satellite to automobile link. At the present time there are no in-orbit commercial satellite facilities available in the United States to support system development and equipment testing.

In order to emulate the satellite signals, CD Radio requested and obtained an FCC experimental license to establish and operate a group of low power terrestrial transmitters in the 2310-2360 MHz band. Under this license the satellite signal is emulated by a network of low power transmitters mounted on tall building rooftops. The automobile satellite radio receiver was implemented using VSAT terminal technology and a portion of the existing automobile audio system. The CD Radio operator interface (i.e., radio controls and displays) and antenna were specially built to reflect the CD Radio design.

The technology employed is the same as required to implement the final system. Application of this technology to the final system requires miniaturization and productizing for volume consumer product manufacturing.

3.2 FCC LICENSING

The implementation of the CD Radio DARS experiment required experimental (temporary) FCC approval to operate a digital data transmission network in the 2 GHz band. Under this license CD Radio use of the S-band for this experiment is limited to secondary or non-interfering status relative to the current primary users of the band. The experimental license also included approval to operate a Ku-band uplink using commercial satellite transponder capacity. The Ku-band is used to transmit the compressed music channels from the programming facility to the 2 GHz rooftop transmitters. The CD Radio experiment operates in two bands:

14 GHz Band	Satellite uplink transmitter in the domestic Ku-band from the CD Radio programming facility at 1001 22nd Street NW in Washington, DC to the rooftop transmitters in Virginia.
2 GHz Band	Emulated satellite signals for transmission to the car.

The license allows test sites to be selected within a 50 mile radius of the center of the major metropolitan areas in the United States. No sites may be located close to the Canadian or Mexican borders. System testing under this license can be performed in or near major metropolitan areas across the country utilizing the terrestrial emulation of the satellite signal and a receiver equipped automobile. A list of the approved metropolitan areas is contained in Table 3-1. This allows CD Radio to test its system in geographically diverse areas and climates within the continental United States.

In this experiment CD Radio was the first commercial entity to use the spectrum allocated to satellite DARS in the United States at WARC 1992 and the first to demonstrate satellite DARS.

3.3 TEST SYSTEM IMPLEMENTATION

3.3.1 General

The initial system experiments were performed in the Washington, DC metropolitan area utilizing a terrestrial emulation of the satellite signals and an S-band receiver equipped automobile. The emulated satellite signal was in the 2310-2360 MHz band assigned for satellite DARS in the U.S. at WARC-92. This signal was emulated by a network of low power transmitters mounted on tall building rooftops. The automobile satellite radio was implemented using customized VSAT terminal units integrated into the existing car audio system. The existing dashboard AM/FM car

Table 3-1 Approved Testing Areas

CITY	LATITUDE			LONGITUDE		
	°	'	"	°	'	"
Atlanta, GA	33	45	10	74	25	53
Boston, MA	42	21	24	71	03	75
Chicago, IL	41	52	28	87	38	22
Cincinnati, OH	39	06	07	84	30	35
Cleveland, OH	41	29	51	81	41	50
Dallas/Ft Worth, TX	32	47	00	96	47	37
Denver, CO	39	44	58	104	59	22
Detroit, MI	42	19	48	83	02	57
Houston, TX	29	45	26	95	21	37
Indianapolis, IN	39	46	07	86	09	46
Kansas City, KS	39	04	50	94	35	20
Los Angeles, CA	34	03	15	118	14	28
Louisville, KY	38	14	47	85	45	49
Miami, FL	25	46	37	80	11	32
Minneapolis, MN	44	58	57	93	15	43
Nashville, TN	36	09	33	86	46	55
New Orleans, LA	29	56	53	90	04	10
New York, NY	40	45	06	73	59	39
Orlando, FL	28	32	42	81	22	38
Philadelphia, PA	39	56	58	75	09	21
Phoenix, AZ	33	27	12	112	04	28
Portland, OR	45	31	06	122	40	35
Saint Louis, MO	38	37	45	90	12	22
San Diego, CA	32	42	53	117	09	21
San Francisco, CA	37	46	39	122	34	40
Seattle, WA	47	36	32	122	20	12
Washington, DC	38	53	51	77	00	33

radio was adapted to work with satellite DARS by adding of a full set of CD Radio display and control functions. A small, low gain satellite antenna was specially designed and manufactured to reflect the CD Radio design. A block diagram of the CD Radio Test System is contained in Figure 3-1 and a technical details on the CD Radio Test System are contained in Attachment A3 of this report.

3.3.2 Signal Source

The CD Radio system provides subscribers with 30 narrowcast channels of CD-quality music programming. This programming is digitally compressed and multiplexed along with a control channel for transmission on a single RF carrier. The control channel contains user activate/de-activate instructions and music selection data. The data rate for each of the 32 multiplexed channels (30 music channels and 2 control channels) is 128 kb/s, resulting in a total information rate of 4.096 Mb/s. In the CD Radio system this multiplexed bit stream is encoded by a convolutional forward error correction (FEC) encoder to enhance link performance.

In this experiment approximately 25 minutes of programming for each of the 30 channels was stored on a SUN workstation. Stereo music from the CD Radio compact disc library was captured on tape, compressed off line, stored on computer hard disk, multiplexed, convolutionally encoded for rate 1/2 FEC and interleaved. Each music selection is characterized by a data block with 96 alphanumeric characters containing artist, song title, album title, CD Radio library number, and CD number. This information is stored on the SUN workstation disk and transmitted in the control channel for display by the car radio. During tests the SUN workstation output a 8.192 Mb/s digital bit stream to a satellite modem for transmission. A block diagram of the CD Radio signal source is shown in Figure 3-2

CD Radio prepared play lists for approximately 25 minutes of music for each of its 30 different music formats (Table 3-2) and assembled a library

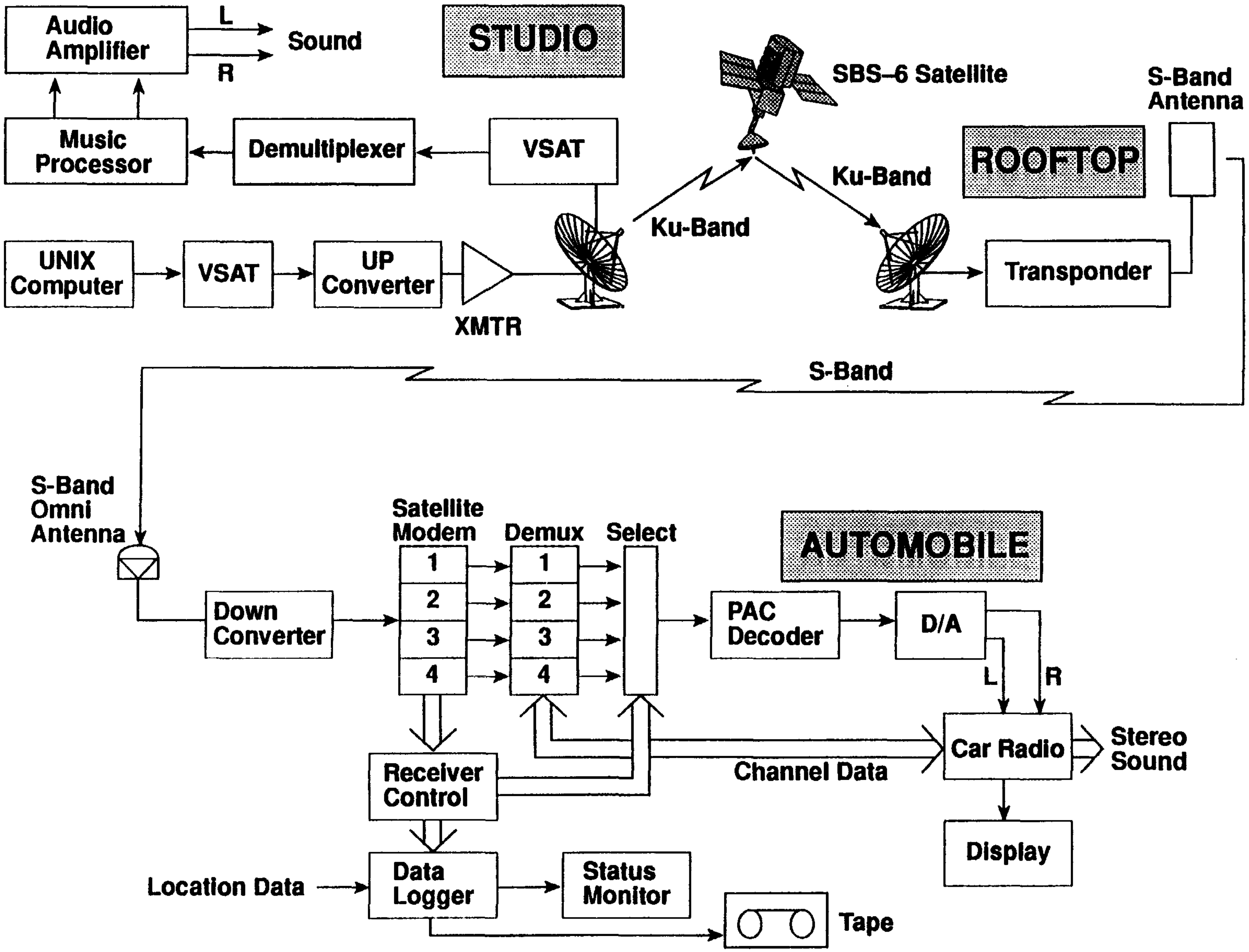


Figure 3–1 CD Radio Test System — Block Diagram

CD RADIO INC.

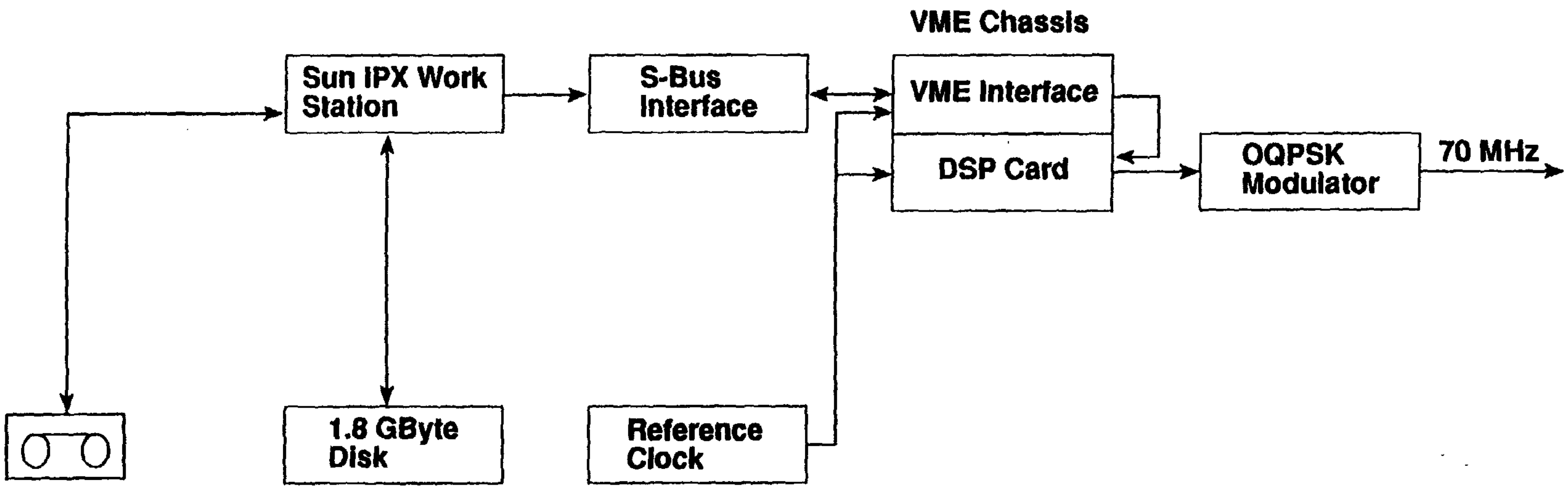


Figure 3–2 Signal Source

Table 3-2 CD Radio Music Format List

1	Symphonic	16	Latin Rhythms
2	Chamber Music	17	Reggae
3	Opera	18	Hip-Hop/Rap
4	Today's Country	19	Dance
5	Traditional Country	20	Songs of Love
6	Contemporary Jazz	21	Singers + Strings
7	Classic Jazz	22	Beautiful Instruments
8	Blues	23	Heavy Metal
9	Big Band/Swing	24	Album Rock
10	Top of The Charts	25	Alternative Rock
11	Classic Rock	26	New Age
12	50's Oldies	27	Broadway's Best
13	60's Oldies	28	Gospel
14	Folk Rock	29	Children's Entertainment
15	Latin Ballads	30	World Beat

of compact discs. The music selections are fully representative of the wide variety of sound material planned by CD Radio. Selections range from Heavy Metal to Symphonic, from 50's to Reggae, from Top of the Charts to Blues. A complete play list is contained in Attachment A4 of this report.

Music for each channel was captured on DAT tape in direct digital mode, compressed into a 128 kb/s bit stream and stored on computer tape. Compression was performed using the AT&T Bell Laboratories' Perceptual Acoustic Coder (PAC) algorithm running on a SUN SPARC II workstation. AT&T's PAC is a recently developed highly efficient software algorithm based on psychoacoustic music compression. This algorithm is the first true joint stereo audio coder. A block diagram of the PAC processor is shown in Figure 3-3. In laboratory tests at 128 kb/s PAC has been shown to provide CD-quality sound at better than ISO-Layer 3. The decoding algorithm is optimized for cost effective single chip implementation. Additional technical information on the PAC alogrithm are provided in Appendix A4 of this report.

The compressed music tape files and control channel data were then loaded on a 2.0 Gbyte hard disk connected to a SUN IPX workstation. The SUN performed multiplexing, rate 1/2 convolutional encoding and interleaving on the stored files. This processing resulted in the disk holding files containing approximately 25 minutes of the CD Radio digital baseband signal.

In the experiment the SUN output a serial bit stream at 8.192 Mb/s to a ComStream CM 236 satellite modem. The satellite modem was modified to operate at rates up to 8 Mb/s input rate and to bypass its internal convolutional encoder. The resultant 70 MHz OQPSK signal was fed to a Anghel UCS14-001-2 up-converter for conversion to Ku-band.

3.3.3 Signal Distribution and Transmission

The Ku-band carrier was amplified in a 100 W TWT amplifier (Xicom

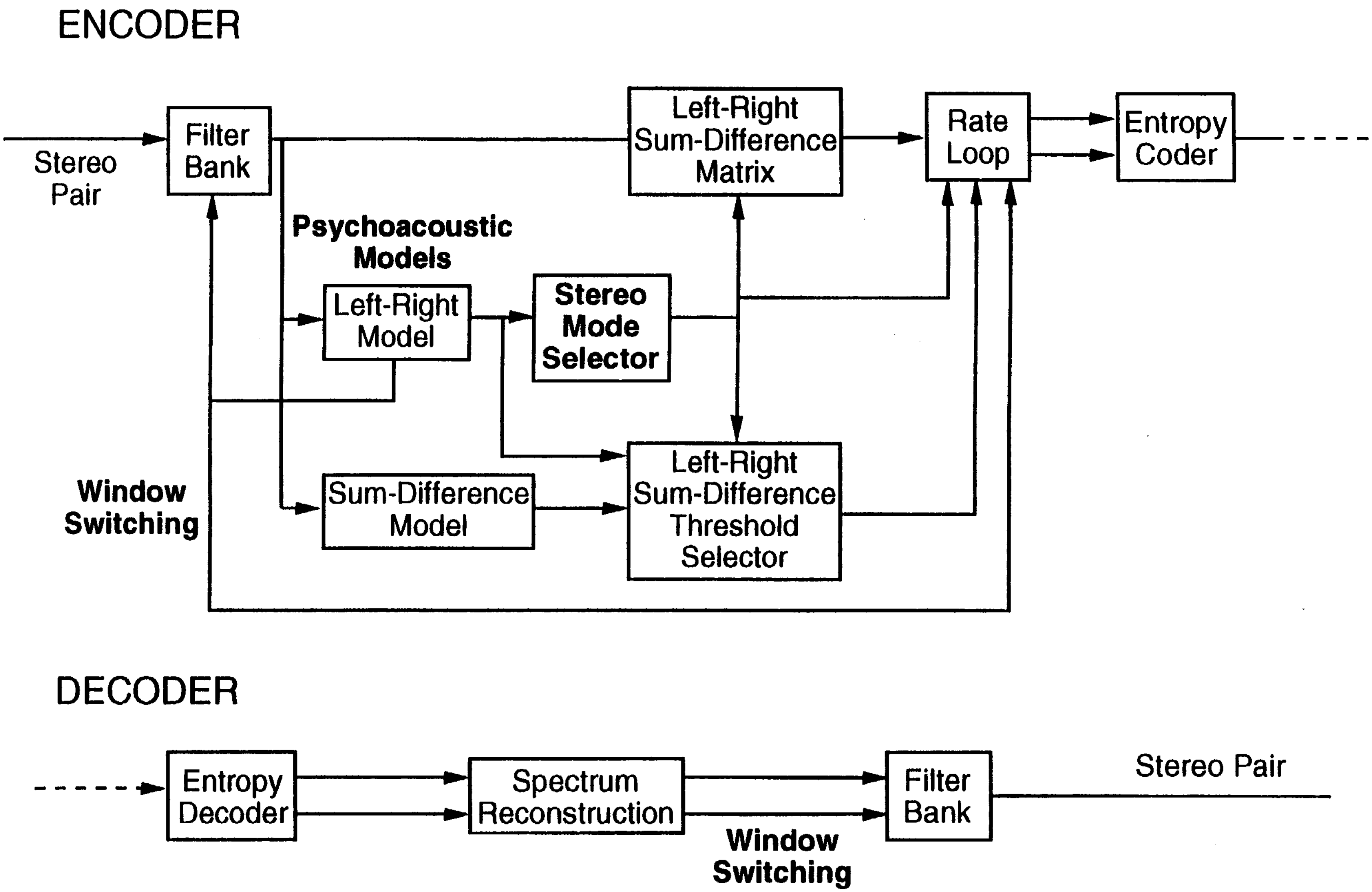


Figure 3-3 AT&T PAC Processor - Block Diagram